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Test of the Infrared Wide-Field Camera OMEGA2000 and its Application for an Extragalactic Survey

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Abstract
The near-infrared wide-field camera OMEGA2000, mounted on the 3.5m telescope at Calar Alto is presented here. We give an overview on the first results of its scientific operation for the MANOS project. We discuss briefly the redshift and spectral energy distribution of the red bright galaxy sample detected in one of the COMBO-17 fields.
Keywords: *OMEGA2000, HAWAII-2, COMBO-17, MANOS*

1 Introduction

OMEGA2000 is a prime-focus, near-infrared (NIR), wide-field camera, mounted on the 3.5m telescope at Calar Alto. The camera uses a 2k×2k HAWAII-2 Focal plane array with a sensitivity from z to K band. Here we present the the camera system and give a short overview on its performance test. We also report the preliminary results of the MANOS project (**MPIA NIR** and **O**ptical **S**urvey), a scientific application using the OMEGA2000 instrument. Then we discuss the improvement in the measurement of the astrophysical properties of its galaxy sample due to the application of the NIR data besides a pre-existing optical data base. The first results of bright infrared galaxies observed in one of the field of the COMBO-17 project are described. We present the redshift distribution, clustering properties and real nature of the Extremely Red Objects (EROs) detected in this field as well.

2 OMEGA2000

The optics and the detector of OMEGA2000 are enclosed in a cryostat which cools these parts to the operating temperature of 77 K with liquid nitrogen and insulates them from the warm telescope mirrors, structure and dome [Baumeister et al. (2002)]. The complete camera system consists of this cryostat, the detector with its mount plate, the optics with the filter wheels, the baffle system and the readout electronics.

The OMEGA2000 instrument uses a HAWAII-2 2kx2k Focal Plane Array (FPA), which belongs to the new generation of the large format NIR image sensors developed by the Rockwell company. It is a low-capacitance HgCdTe detector array mated to a low-noise CMOS silicon multiplexer via indium interconnects. The quantum efficiency of the detector is high enough for scientific purposes in the wavelength range 0.8-2.5 μm. The image sensor is built up in electrically independent quadrants, which are controlled in parallel. We implemented various readout modes with correlated double sampling for the FPA and optimized them to obtain the best image quality with a high frame rate [Kovács et al. (2004)]. We tested the operation of three speciemen from the HAWAII-2 family in these readout modes and compared their performances with each other. We determined the typical characteristics of the FPAs which were similar for each of them. We measured low readout noise of 10 e^- on the average and gains of about 5 e^-/ADU by plotting their photon transfer curves. The low readout noise allowed us to operate the camera with background noise limited performance (BLIP). The number of dead pixels were under 2 % of the total pixel number for each FPA and they could be masked out from the science frames. We found the low dark current to be dominated by the noise of the readout electronics. We determined the linearity of the FPAs and measured their full well capacities to be about 200,000 e^-.

Since the primary science goal was for OMEGA2000 to be a NIR wide field imager, producing high quality images with the largest reasonable pixel scale, it is placed at the prime focus of the telescope. The optics of the camera consists of a cryogenic focal reducer providing a $15.4'' \times 15.4''$ field of view with a resolution of $0.45''$/pixel [Baumeister et al. (2002)]. The center to corner image distortion was measured to be $0.12''$ for the maximum distance of $600''$, which is less than one pixel.

The OMEGA2000 camera contains 17 filters of 3 inch diameter for wavelengths between 0.8 and 2.4 μm and one closed blank, which are distributed over three filter wheels. The filter unit containing the wheels, the cryogenic stepper motors and the locking/cooling mechanisms is placed between the detector and the focal reducer.

OMEGA2000 is equipped with a baffle system to minimize the amount of background radiation reaching the detector in the K band (Baumeister et al., 2002). The baffle system consists of one cold and two warm mirror baffles. They prevent the detector from seeing the warm surroundings, which improves the S/N ratio in the K band. For J and H band observations, one of the mirror baffles can be moved closer to the dewar to a position where it does not vignette at all [Bailer et al. (2000)].

3 Scientific Applications

One of the first scientific applications if the OMEGA2000 camera is the MANOS Deep Field Survey, called COMBO-17+4 NIR, which was planned to extend the results of the COMBO-17 project to higher redshifts. The NIR extension of the COMBO-17 survey is to produce multi-band data in 4 NIR filters for three equatorial fields covering 0.77 deg^2 already observed by COMBO-17 [Wolf et al. (2003)]. The survey is designed to use a filter set of the medium-band Y, J_1(1190/130nm), J_2(1320/130nm), and the broad-band filter H. In order to combine the existing optical database from COMBO-17 with observations in the four NIR bands, 10σ magnitudes in the four NIR bands with $Y = 22.0$, $J_1 = 21.2$, $J_2 = 21.0$, and $H = 20.5$ (Vega mag.) have to be obtained.

Although the first observations of this survey produced only J_1- and H-band imaging in the COMBO S11 field, restricting the original project to the COMBO-17+2 NIR, the enlarged color space of the measurement allowed us to derive redshifts for the galaxies detected in this field up to $z \sim 2.1$. We studied the improvement in the redshift determination and the quality of fittings of the COMBO-17+4 NIR spectral template library on the measured fluxes for galaxies due to the supplement of the optical data with the NIR-band colors. We chose a population from the R- and H-band selected galaxy sample in the COMBO S11 field for which the variation in the astrophysical properties derived from the optical and the optical+NIR data sets was significant. We studied the differences between the photometric redshifts derived from the optical and NIR-supplemented optical fluxes and analyzed the results of the SED and extinction evaluation for the original and the extended data set. We found the galaxies with the 4000 Å break in their spectra redshifted to the redward end or even out of the optical regime, i.e., at $z > 1.2$, had a significant improvement in the redshift and SED determination. The measurement based on only optical bands could not detect the spectral features of their old stellar content at these redshifts. These galaxies were identified mainly as actively star-forming systems with large variations in their dust reddening and some of them were dusty early-type or evolved spiral galaxies at redshifts between 0.7 and 1. By including the NIR colors in optical ones, we detected mainly advanced spiral galaxies from Sa to Sbc with low extinction at higher redshifts and some starburst galaxies with more dust as well.

By extrapolating this preliminary analysis to the total planned survey data, we expect the extension of wavelength coverage and the increase of the number of bands will have a deep impact in the redshift and SED determination for at least 15% of the entire galaxy population detected in the COMBO-17 fields.

4 Preliminary Results

We investigated how the relative fractions of the spectral types in our bright infrared galaxy sample ($H < 21.4$) with $M_B < -20 + 5\log h$ has been evolving from $z \sim 2$ to present, comparing with the development of the morphological distribution observed in other surveys at $z \sim 0$, and how this is related to the structure formation history. We determined the redshift distribution of bright infrared galaxies observed in the COMBO S11 field and analyzed the evolution of their number counts for four classes of galaxies defined by their restframe colors. A decline in the number of the old elliptical and evolved spiral galaxies at $z > 1.5$ was found, whereas the actively star-forming galaxies become the dominating population at $z > 1$. This is in a broad agreement with earlier results. In the analysis of the galaxy population with $M_B < -20$ in the Hubble Deep Field North and South, Conselice et al. (2005) recognized similar tendencies in the evolution of the co-moving densities of ellipticals, spirals, and peculiars to those we found in the case of four spectral types originally defined in the COMBO-17 survey [Wolf et al. (2003)]. They showed a gradual decrease of peculiar galaxies at the expense of the normal Hubble types and considered it as circumstantial evidence that at least some fraction of ellipticals and spirals at lower redshifts originate from peculiar galaxies. The change of the relative fraction of E-Sb-type galaxies and the actively star-forming systems defined via their bluer rest-frame colors probably indicates that some massive early-type galaxies originate from peculiars at high redshifts. The dramatic decline of the E-Sb type systems with increasing redshift also demonstrates the important role of the passive evolution of galaxy colors besides the merging processes in the variation of the relative fractions of different spectral types.

The NIR-band-extended wavelength range of the measurement between 700 nm and 1300 nm covers the most interesting part of the spectra for EROs, which may help to answer the question of whether the extreme colors of these objects can be attributed to the dust-extinction in starburst galaxies or the EROs are early-type galaxies dominated by an old stellar population. For the EROs in our galaxy sample selected with $R{-}H < 4$, we measured similar redshift distribution and clustering properties to those derived in other NIR surveys. The sharply peaked redshift distribution we obtained might suggest that our color cut selects mainly early-type galaxies with advanced stellar population. The high clustering amplitude, $A(1'') = 0.33$, we derived for $H < 20$ shows that our EROs are much more positively correlated than expected for blue galaxies at high redshifts. This indicates that they are indeed early-type galaxies at $z \sim 1$. As a result of the multi color classification, we find that our ERO sample does not contain starburst galaxies at all, confirming the results of earlier observations in the Las Campanas Survey [Firth et al. (2002)]. This is in good agrement with the two-color separation methods we applied as well. However, the total absence of the star-forming systems may also be attributed to the spectral template library used in the COMBO-17+2 NIR multi-color classification.

5 Summary and Outlook

We have given a brief overview on the OMEGA2000 instrument and the first results of the MANOS project using this camera. We described the improvement in the measurement of the astrophysical properties of galaxies achieved in this survey by applying the NIR data produced in a COMBO-17 field. Then we presented the redshift evolution of the number counts for bright infrared galaxies and studied the nature of EROs in our galaxy sample. We obtained similar results for the both types of galaxy samples to those derived in other surveys.

Besides the extention of the redsift regime available for optical galaxy surveys, there are other promising advantages of the supplement of the COMBO-17 data set in NIR regime. We expect a considerable improvement of the stellar mass estimation in galaxies. Even in the redshift range $0.7 < z < 1.1$, the old stars have a dominant contribution for galaxy spectra only in the NIR regime. Therefore, the data provided in COMBO-17+4 NIR will significantly improve the determination of the stellar mass in galaxies. The NIR-band filters with the broad I-band filter seem useful for searching AGNs at redshits $z > 6.5$ as well, and measure their rest-frame B-band and 250 nm luminosity functions out to $z \simeq 2.6$ and 5.5. This will be useful for studying the redshift evolution of AGNs in the Universe. The COMBO-17+4 NIR survey has also prospects for the detection of extremely red stars (brown dwarfs), as a consequence of the improvement in the object classification due to inclusion of the NIR bands.

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